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New Space Industries For The Next Millennium

Compiled by
D.V. Smitherman, Jr.
Marshall Space Flight Center, Marshall Space Flight Center, Alabama

December 1998

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Artwork: All illustrations are NASA artwork by Pat Rawlings, Science Applications International Corporation.

Cover artwork: Space Business Park—this multipurpose commercial space station features a space hotel with two counter-spinning rings to simulate lunar gravity, a core backbone of zero gravity state rooms, and two inflatable arena spheres. Each module is equipped with an emergency escape capsule or life boat that becomes part of the living space within the suite. Designed for approximately 200 people, travelers typically enjoy 1-wk cruises through space that includes a wide variety of activities, entertainment, and spectacular views of the Earth and stars. Power is produced through the circular solar concentrators shown in the foreground.

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ACRONYMS

AIAA	American Institute of Aeronautics and Astronautics
CP	Conference Paper
CRV	Crew Rescue Vehicle
CSC	Commercial Space Center
CSTS	Commercial Space Transportation Study
DOC	Department of Commerce
DOT	Department of Transportation
EELV	Evolved Expendable Launch Vehicle
ETO	Earth To Orbit
GEO	Geostationary-Earth Orbit
EVA	Extra Vehicular Activity
FAA	Federal Aviation Administration
GPS	Global Positioning System
ISS	International Space Station
MEO	Middle Earth Orbit
NASA	National Aeronautics and Space Administration
OMV	Orbital Maneuvering Vehicle
OTV	Orbital Transfer Vehicle
RBCC	Rocket-Based Combined Cycle
RLV	Reusable Launch Vehicle
SAIC	Science Applications International Corporation
SBP	Space Business Park
SSP	Space Solar Power
TM	Technical Manual

1. INTRODUCTION

New Space Industries For The Next Millennium is a final report of the findings from the New Space Industries Workshop held in Washington D.C. in February 1998. The primary purpose of this workshop was to identify what must be done to develop new markets, and to generate plans, milestones, and new organizational relationships designed to facilitate the goal of space development. This document provides a summary report on the results of that workshop and is not intended as a statement of NASA or Government policy.

Previous studies had shown great potential for the development of new markets in space, and a great need for coordination and formation of infrastructures to facilitate the growth of new space businesses. The New Space Industries Workshop brought together Government, academia, and industry participants from several previous studies and other professionals interested in the development of space for commercial purposes. Their participation provided input into the role of Government and industry in space development as well as the technology needs that will enable space development.

The opening of the frontier of space—not just to Government missions, but to private individuals and commercial business—is a challenge of overarching importance. It is our hope that the workshop and this final report continue in earnest the process of identifying and overcoming the barriers to large-scale public access and development of space in the early years of the next millennium.

2. NEW SPACE INDUSTRY MARKETS

2.1 Travel and Entertainment Market

The terrestrial travel and entertainment market is a very large, multibillion dollar industry serving both business and leisure travel, and entertainment industries. This market has been successful because it addresses not only point-to-point business travel requirements, but also customer needs and motivations for adventure, personal growth, and the fulfillment of dreams for the future. Public space travel and tourism could follow a similar path for expansion into the space travel era with vehicles and destination facilities designed and developed for both business and leisure travel, and entertainment.

Adventure travel to unusual or unique destinations often involves some risk, excitement, and physical involvement, as well as educational opportunities where you can learn by doing or participating in out-of-the-ordinary activities. For the space traveler this could mean working on board in the maintenance and operations of a space facility as part of the tour, or participating in scientific research, Earth observations, or asteroid hunting. These activities work toward fulfilling the customer’s dreams of the future with new freedom—a pioneer spirit—opening up a new frontier for a new way of life. These are some of the motivations that will open up the space travel industry.

2.1.1 Key Issues

The primary issue to be resolved for the travel and entertainment market is providing public access to affordable, dependable, and reasonably safe transportation. From the nearer to the very far-term this includes: point-to-point suborbital transportation for round the world travel to any major destination on Earth in 90 min for passenger and package delivery services; Earth-to-orbit (ETO) transportation for access to existing and new space destination facilities; in-space transfer transportation including lunar orbit tours, as illustrated in figure 1, and access to the lunar surface.

Figure 1. Blue Moon Tours. A concept for a round-trip cruise from Earth orbit to the moon and back.

As transportation to space for the general public becomes a reality, commercial access to on-orbit facilities should include access to the *International Space Station* (*ISS*), *Mir*, and privately developed stations like the space business park shown in the cover artwork. Future facilities will include large volume habitats, with safety, traffic control, and supply systems comparable to the building construction, utility systems, and transportation standards available on Earth.

Some of the ideas put forward at the workshop that might help promote a space travel and entertainment market include:

- Market surveys and studies focused on public space travel needs.
- Proactive public policy and legislation to promote space travel for the general public, including NASA advocacy of public space travel.
- NASA and Government prioritization of ETO technology developments to enable public space travel, including X-vehicle developments compatible with passenger service for the general public.
- Overflight and reentry regulations merged with air traffic control.
- Reasonable regulations for passenger carrying reusable launch vehicles (RLV's).
- Appropriate medication testing (e.g., Terfenidine and Promethyzine) for public use to prevent space sickness.
- High-fidelity telepresence to experience space from the ground.
- Limited liability insurance and Government guaranteed loans to reduce risk, and cost of new space investments.
- Appropriate incentives for space investments, (e.g., tax related).

More ideas related to the travel and entertainment market can be found in the section on "Space Business Parks Infrastructure" where the travel destination is discussed. Space should be viewed as an opportunity for development of a place to live, work, and prosper as we do here on Earth. Making low-Earth orbit (LEO) accessible for business and leisure travel, and entertainment, will begin the process toward the development of space for everyone.

2.2 Space Solar Power Market

Space solar power (SSP) could be a viable, competitive augmentation to existing terrestrial energy sources providing, clean solar electric power to the population of Earth in the 21st century. This abundant, carbon-free energy source could help mitigate the growing concern many people have about an increased carbon dioxide content in our atmosphere. This system could also create energy-rich space facilities and transportation systems with many new products produced by terrestrial, space, and lunar related industries.

The potential benefits of SSP include: reduced environmental impact due to fossil fuel energy generation, development of power-intensive space activities, extensive support to third world development through the "instant infrastructure" that beamed energy from space can provide, potentially unlimited source for global power, and the potential reduction of "risk related" barriers to new power plants in developing countries. In addition, the unlimited energy supply that space could provide has the potential of freeing up hydrocarbon resources for other important purposes.

2.2.1 Key Issues

The key issue for SSP is the large development cost and associated financing for a complete system. SSP, because of its location, has global potential which implies development scales to accommodate a growing global market. There will need to be returns on investments that are competitive in capital markets for investments with a similar degree of risk. Reducing the risk will reduce the cost for development, and in return, increase its competitiveness with established terrestrial power systems.

The benefit is more than just a cost goal. SSP offers a potential for a clean, safe, global power infrastructure that can satisfy long-term power needs of the industrially developed and developing populations on Earth and in space.

Some of the ideas put forward at the workshop that might help promote an SSP market include:

- A comprehensive global energy needs analysis.
- Technology developments and demonstrations in many areas, and proof-of-concept flight experiment missions.
- Education of the public, domestically and internationally, concerning SSP on environmental, societal, and safety issues.
- Proactive policies and legislation that recognize the global needs for SSP.
- Near-term allocation of proper bandwidth for power transmission.

Leading concepts for SSP include the solar disk and Sun tower configurations as shown in figure 2. The solar disk is a spinning disk comprising thin-film soar arrays that collects energy in geostationary Earth orbit (GEO) and transmits it to a single equatorial receiving station on the ground. The Sun tower is part of a constellation of inflatable collectors that concentrate and transmit power to stations around the globe. Sun tower constellations could be deployed in LEO, middle-Earth orbit (MEO), or in GEO with the capability to transmit power to low- and high-latitude sites on Earth.

Alternatives to SSP include space-based nuclear power and fusion power systems among others. Fusion is in the technology development phase and is not expected to be viable for commercial use in the next 30–40 yr. Space-based nuclear power systems have been demonstrated and will be needed for lunar developments and deep space missions. A space-based nuclear power infrastructure is an alternative to SSP that might

Figure 2. Space solar power. Depicts solar disk and Sun tower configurations for solar power satellites.

be considered if studies show that a space-based energy infrastructure concept is feasible, but that solar power technology is either too expensive to develop or inadequate to meet performance requirements.

Development of new space power energy systems is a long-term and deliberate technology development effort that should be pursued vigorously. It is believed that this market will become more important early in the next century as some oil resources become depleted and the environmental concerns surrounding our current power systems continue to grow.

2.3 Satellite and Space Transfer Services Market

The potential markets for reusable on-orbit transfer spacecraft include assembly, construction, maintenance, servicing, and in-space transportation. Assembly and construction includes work on large platforms, space stations, space business parks, and space power platforms, performing welding, deployment, installation, mating, and joining of premanufactured components to form larger systems. This is the business concept underlying the "rent-a-robot" shown in figure 3. Maintenance opportunities of other systems include observation, surveillance, inspection and assessment, replacement of components, and upgrade of modular systems. Servicing opportunities include refueling, power/battery replacement, food, water, equipment, support, shield repairs, and removal of debris, contaminants, and trash. In addition, in-space transportation includes orbital transfer and rescue for moving spacecraft from orbit to orbit, human in-space transportation, transfer from station to station, LEO to station, rescue and salvaging operations, space rides for tourism and entertainment, and spacecraft to spacecraft transfers. Figure 4 shows space transfer vehicles based at a propellant storage platform that could also be used for temporary storage of other items for return to Earth or reuse in space.

2.3.1 Key Issues

Servicing must meet customer needs for on-time, low-cost, effective, and efficient operation, with reliable, safe rendezvous, abort and return modes. Some of the ideas put forward at the workshop that might help promote a satellite and space transfer services market include:

- Adoption and use of serviceable satellite standards by Government and industry including reusable orbital transfer vehicle (OTV) and orbital maneuvering vehicle (OMV) demonstrations and standards.

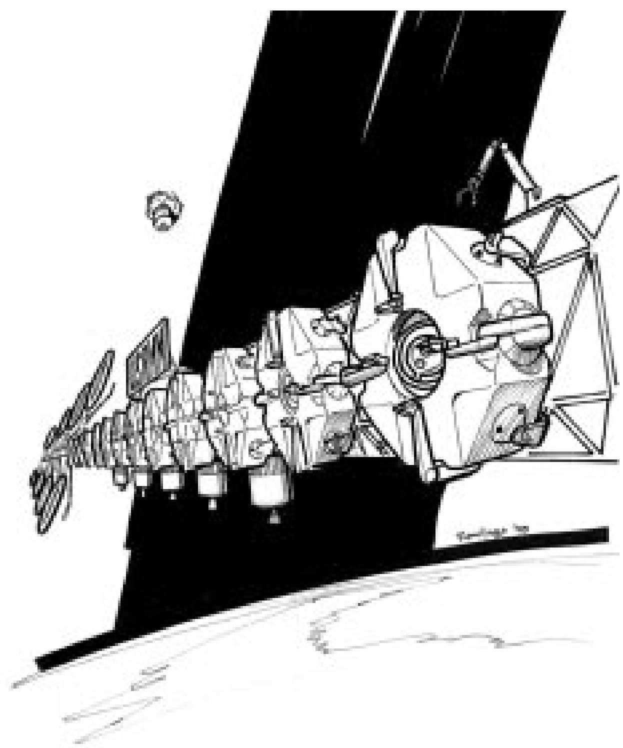


Figure 3. Rent-a-robot. A facility where autonomous or teleoperated robots can be leased for construction or repair work.

Figure 4. Satellite and space transfer services. Generic reusable tugs boost new and refurbished satellites from an orbital satellite maintenance, repair, and refueling facility.

- Orbital debris mitigation and cleanup for protection of space assets.
- Advances in telepresence, virtual reality, and remote control of spacecraft for inspection and space rescue purposes.
- Government anchor tenancy in a commercial logistics supply and servicing system for space station and Government-owned satellites.
- Proactive Government policies and legislation for tax credits, consortium support, trade promotion, education, and endorsement.
- Proactive Government policies and legislation for commercial development of reusable systems, resupply systems, and permanent space infrastructure development.
- Autonomous and remote construction systems for assembly, repair, and maintenance of modular and upgradable systems.
- Creation of a space bank to provide financial backing and Government guaranteed loans.

The market for satellite and space transfer services is very broad and will ultimately require a fleet of multipurpose vehicles that can provide for the transportation and service needs similar to the broad range of markets that Earth-based vehicles provide for multiple markets on Earth. Some parts of this market are believed to be viable today at current space transportation prices. Government policy and legislation can enable this market in the near term.

2.4 Research and Development in Space Market

The concept behind the research and development (R&D) in space market is the need for orbital laboratories that are free from the access and use constraints inherent in Government owned and operated facilities. Facility access has been, and will continue to be, severely constrained even with the coming of the *ISS*. New commercial laboratories like those proposed by SpaceHab, in combination with the new commercial transportation systems as envisioned by Lockheed's Venture Star and the X-Prize participants could open new markets for commercial R&D by providing access when needed, at a set cost that is predictable, with facilities that are secure and independent of Government controls.

2.4.1 Key Issues

Routine, dependable access to space laboratory facilities is the primary problem inhibiting broad industry utilization of space for R&D of new products. Some of the ideas put forward at the workshop that might help promote the in-space R&D market include:

- Routine, reliable transportation to space including a fixed price for transportation and use of existing facilities on the Space Shuttle and near-term *ISS* facilities.
- A standard decision process for access to limited Government facilities.
- Technology development and demonstration of autonomous and human tended free-flyer microgravity platforms as illustrated in figure 5.
- Government incentives for development and use of commercial facilities.

Private laboratories, both industrial and academic, could support the development of new products and services in the microgravity and/or high-vacuum environment of space. Both terrestrial and nonterrestrial materials could be made available for in-space processing to demonstrate new products, technologies, and new business concepts. This in turn will lead to the development of a new space manufacturing market as discussed in the next section.

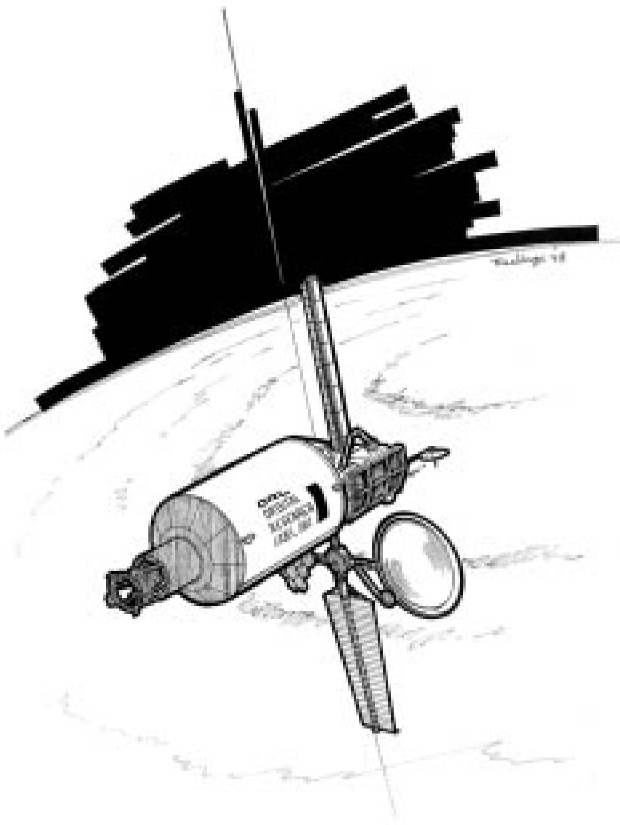


Figure 5. Microgravity platform. A free-flying lab for testing of technologies and development of new products in a vacuum, radiation, and/or microgravity environment.

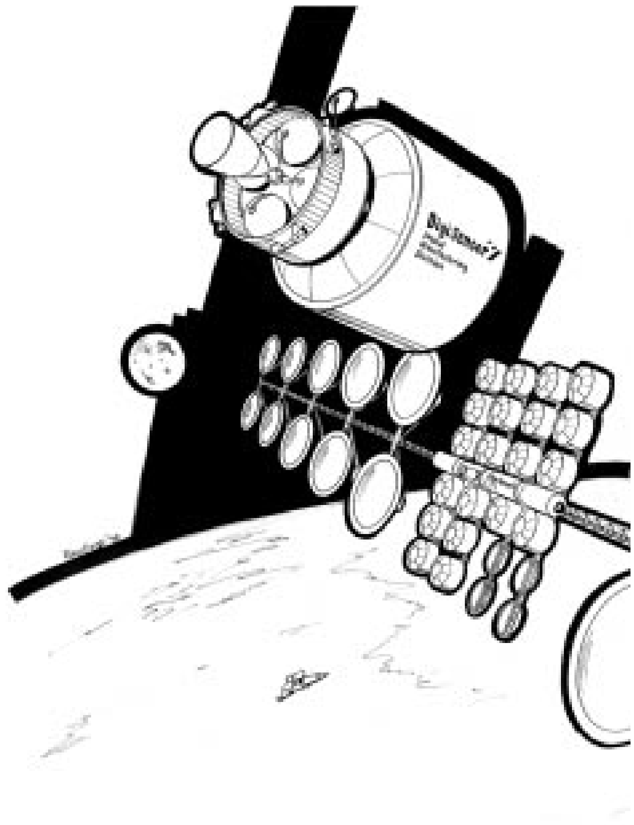


Figure 6. Space manufacturing. An orbital facility for manufacture of multilayer sensors. Individual modular manufacturing units are returned to Earth at the end of the production cycle.

2.5 Space Manufacturing Market

Following the initial R&D in space, the actual mass production of new products in space is envisioned as the space manufacturing market (see fig. 6). The two fundamental requirements for any successful product are that there be a market sufficiently large to generate an acceptable return on the initial investment in R&D facilities and capital equipment, and that the viable market price of the product be high enough to pay recurring and nonrecurring costs to return a reasonable profit to the investors. The lower the risk in meeting both of these requirements the better.

There are two types of products which will allow a new space manufacturing business to prosper: (1) Products for terrestrial use whose value-per-unit mass is extremely high and which have no comparable terrestrial manufactured competitors, and (2) products for use only in nonterrestrial locations.

The “ground rules” that products manufactured in space must have intrinsically high value-per-unit mass and no lower-priced terrestrial competitors, limit product opportunity considerations dramatically. Within these constraints, the working group identified four major market segments that can be explored: (1) Industrial markets for super-pure exotic-material semiconductors for fault-free microprocessors and memory storage chips, multilayered composite structures for sensors and laser components, and unique chemical materials such as catalysts, extremely high-temperature alloys, and impurity-free glass, (2) health care markets for unique pharmaceutical products and protein crystals required for drug design via ground-based X-ray crystallography, etc., (3) unique raw materials like asteroid samples and Helium 3 from the moon, and (4) mass market sales of novelty jewelry, souvenirs, etc. to individuals using extraterrestrial materials.

Opportunities for manufacturing products to be used only in space do not yet exist, but could be substantial in the future, to include production of everything needed for in-space use. Specific in-space product opportunities that are more near-term include (1) photovoltaic cells for space-based solar power systems, (2) the solar power satellites themselves, (3) replacement parts or subsystems for refurbishment of satellites and spacecraft, and (4) water and propellant production from lunar materials.

2.5.1 Key Issues

There are two key issues which face any and all space manufacturing enterprises: (1) Lack of the necessary infrastructure at acceptable cost levels and response times, including transportation, utilities, and facilities, and (2) lack of sufficient market prospects. Technology and policy issues exist, but probably do not pose significant barriers to space-based manufacturing facilities once a viable market appears and a low-cost infrastructure becomes available.

Some of the ideas put forward at the workshop that might help promote the space manufacturing market include:

- Technology demonstrations of space resource utilization for space processing and manufacturing.
- Continued development of microgravity tools, manufacturing equipment, and construction systems.
- Continued development of transportation, utility, and facility infrastructures in space.

The potential near-term markets of jewelry, souvenirs, semiconductors, layered materials, health care products, raw materials, and fiber optics, and the long-term markets for mass production of everything needed for in-space use—water, air, propellants, vehicles, facilities, etc.—hold great promise for space manufacturing in the 21st century.

2.6 Space Resources Market

Space resources is defined as natural extraterrestrial material that can be extracted for a profit. There are two general classes of space resources: (1) Materials that carry intrinsically high value for import to Earth, and (2) those that are cheaper to use in space than to launch from Earth. The Sun as a resource for power generation is covered as a separate market for SSP.

The materials that carry intrinsically high value on Earth include gold, platinum, titanium, and other precious metals. Of even greater value in the near-term would be soil from the Moon, Mars, asteroids, and comets for their scientific value and novelty. As an abundance of these materials becomes available, it would be possible to attract mass markets to their novelty as jewelry and trinkets, as referenced in the previous section on space manufacturing.

Space resources that are cheaper to use in space than launched from Earth would eventually include water for propellants and gasses, and metals for product manufacturing and construction in space, as envisioned in figure 7. This market will grow as the space manufacturing market grows and commercial access to the Moon and asteroids becomes available.

Figure 7. Space resources. An asteroid miner excavates ores for use in structures and fuel manufacture. The miner has a mobility system and a resupply vehicle that visits periodically.

2.6.1 Key Issues

A consistent effort to make a comprehensive "solar system geological survey" is needed to identify the resources available at the Moon and near-Earth asteroids, including the theories that ice asteroids, or cosmic "snowballs" may be common. Asteroid detection and characterization for threat mitigation has been identified by many scientists, Government agencies, and the news media as a priority to protect our planet. A consistent effort to identify the asteroid composition would help identify the natural extraterrestrial materials that can be extracted for a profit.

Some of the ideas put forward at the workshop that might help promote a space resources market include:

- Government incentives for commercial identification and extraction of samples from near-Earth asteroids and the Moon.
- Observation systems for asteroid discovery, orbit determination, and remote classification including remote sensing of specific chemical compositions (e.g., platinum and other precious metals).
- Adaptation of mining technology to microgravity and low-gravity environments.
- Material identification, extraction, separation and

processing systems, including in situ processing demonstrations.

- Policy and legislation that provide clear property rights to industry investments in space and reasonable industry claims to space resources.

The space resources market is a near-term market that is not dependent on other infrastructures or breakthroughs. Sample returns have already occurred from the Moon during the Apollo program. Commercial extraction appears to be a real near-term profitable market.

3. NEW SPACE INFRASTRUCTURES

3.1 Space Transportation Infrastructure

The major markets that require space transportation support are the traditional space lift requirements for satellites, *ISS* construction and support, space science, microgravity research, and planetary exploration, and the new potential space industry markets for space tourism, SSP, point-to-point cargo and passenger delivery, space product development, space manufacturing, space business parks, and entertainment. The primary difference between the traditional space markets and the new markets is that the new markets are driving new requirements for high flight rates, dependable service, high reliability, safety, and low cost. These are the characteristics of all transportation systems now in use for ground and air travel today. The space transportation systems of the future should be no different.

3.1.1 Key Issues

The key issues are reliability, risk mitigation, operability, development costs, operations cost per pound, and cost per mission. High reliability is essential in order to get low insurance costs and develop new markets. High flight rates are needed to achieve low cost per pound and conversely low cost per pound is needed to achieve high flight rates. This implies another key issue, which is to develop a financial plan that works through the phase-lag between having the capability and getting the missions/markets.

Some of the ideas put forward at the workshop that might help promote a routine, reliable, and affordable ETO and in-space transportation infrastructure include:

- Development of more ETO and suborbital X-vehicles to demonstrate new technologies and new approaches to space transportation.
- Development of fully reusable one- or two-stage X-vehicles that can be integrated into the existing airline infrastructure and is specifically designed for passenger service.
- Development of X-vehicles and facilities for demonstration of in-space transportation technologies.
- A simplified regulatory process for new commercially developed space vehicles.
- Public policy and legislation that encourages commercial development of space vehicles and support services.
- Government anchor tenancy in commercial space transportation for logistics to the *ISS* and other Government space assets.
- Advanced technologies and systems to demonstrate integrated health management; high-strength, lightweight, low-cost, structures; and high-energy aerobraking and aerocapture systems.
- Propulsion technology investments to include highly operable and highly reusable rocket engines, air breathing rocket-based combined cycle (RBCC) engines, high-energy density propellants, solar-thermal engines, steam rockets, air collection and enrichment systems, nuclear technologies, and propellantless transportation technologies to include electrodynamic tethers and momentum exchange tethers (see fig. 8).

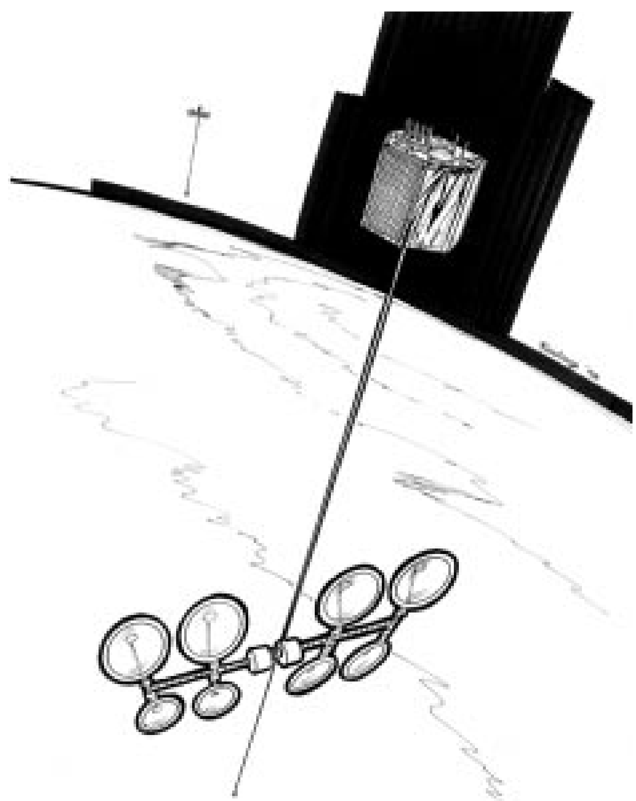


Figure 8. In-space transportation. Two tethered orbital transportation concepts: In the foreground is a spinning tethered space transfer launch system and over the horizon is an electrodynamic orbital maneuvering vehicle.

Incentives for the commercial development of these infrastructures appear possible through technology development for suborbital and ETO passenger-carrying vehicles, Government anchor tenancy of large transportation systems, new requirements for reusable upper stages and transfer vehicles to service Government systems, and new requirements and standard interfaces for commercial propellant delivery with a Government demand for a commercial propellant supply infrastructure. These represent potential near-term commercial markets, but will require Government policy and legislative incentives to realize the full commercial development potential envisioned.

3.2 Space Business Parks Infrastructure

A space business park, such as the illustration in figure 9, is a commercial multiuse space station facility designed for use by compatible commercial business tenants. The purpose of the facility is to provide flexibility that will enable diverse business and recreational activities that, where possible, can share common infrastructure to reduce overall costs and leverage shared resources. The potential for space business parks is one that will provide a means for expanding global economic activity beyond the bounds of Earth and into LEO.

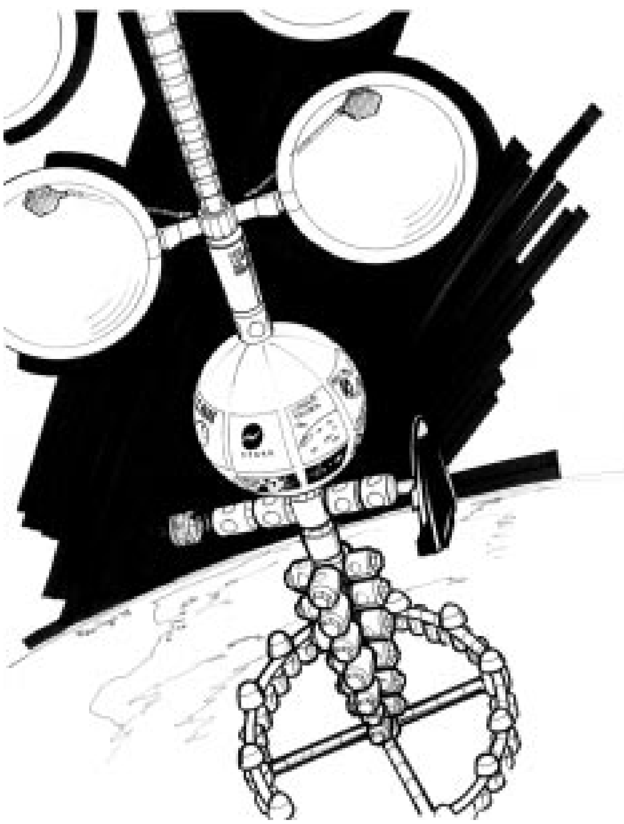


Figure 9. Space business park. A space business park is a commercial multipurpose space station designed for multiple tenants that share common facilities. This facility includes a space hotel with an artificial-g deck in a spinning ring, equipped with small lifeboats, zero-g state rooms, and an inflatable arena sphere.

The potential businesses that could share multipurpose facilities in and around a space business park include: the travel industry for business and leisure travel; the entertainment industry for film production, the arts, advertising, recreation and sporting events; R&D laboratories and space manufacturing facilities using the ultravacuum and microgravity environment for new product development and production; remote sensing and observation of Earth for resource management, and observation of space for asteroid detection; new medical technology development and medical services; and new space transfer and satellite services. The businesses dependent on participation by the general public will be dependent on new ETO transportation systems designed for passenger service. Other business ideas like the space transfer and satellite services, remote R&D laboratories, and Earth observation may be feasible for a human-tended multipurpose platform using current transportation systems.

3.2.1 Key Issues

The number one issue to be resolved is the development of a low-cost transportation system that can evolve to a high flight rate system for passenger travel the way the airline industry operates today. In addition to ETO transportation, there will need to be OTV's for people and payload transfer to and between stations and automated escape and reentry vehicles that operate as lifeboats in the event emergency egress is required from the space business park.

ISS technology is providing standardized modules, nodes, power, thermal, and life support systems that can be used for space business park development. Additional needs include large-volume and variable-gravity facilities to accommodate the adventure travel and entertainment industry. This will lead to environments that can support people, agriculture, and industry in a rotating gravity environment to support life in space permanently. Other needs include a low-cost means to service and resupply the facility with basic utilities such as air, food, water, propellants, power, etc., as is common for Earth-based facilities, and closed-loop regenerative life support systems and propellantless electrodynamic technologies that will minimize resupply needs.

In order to develop and maintain a thriving space business park infrastructure, it will be necessary to put in place a construction and maintenance process that is capable of handling all the components and systems required. This could include hangar bays, construction platforms, propellant platforms, automated and human tended factory modules, new hard-suite extravehicular activity equipment, and better systems for long-term personal hygiene in a microgravity environment. Larger facilities will create a need for better orbital debris management, solar flare weather forecasting, and in-space traffic control.

Some of the ideas put forward at the workshop that might help promote a space business park infrastructure include:

- Adding a commercial module to space station as a commercial consortia partner to the *ISS* program.
- Proactive policy and legislation that encourages utilization of *ISS* technology tooling, and facilities.
- Privatization, leading to commercialization of the space station.
- Safety, security, rescue, and escape systems for personnel including demonstration of orbital debris mitigation, damage detection, and repair.
- Technology development for large-volume construction systems, partial gravity (rotating) mechanical systems, closed-loop life support systems, and large window systems.
- Policies on governance, zoning, administration, and security for privately owned space facilities.

Once the market for space business parks is opened up through transportation, there will be a demand for large-scale orbital facilities that have large volumes and can handle large numbers of people. This market will lead to a demand for expansion from LEO to the Moon, with orbital journeys out and back, and eventually to the lunar surface.

3.3 Space Utilities Infrastructure

Space utilities is a secondary space market for commodities, supplies, and services, supporting the primary users in the space markets. As space development becomes robust, the need for utilities will be critical, and will be analogous to ground-based utilities for terrestrial industries. As markets for utilities in space grow, space utility providers will emerge, providing utilities at a bulk rate that will be more cost-effective than if the users provided their own independent system.

3.3.1 Key Issues

Technology development and demonstration is needed for supply and distribution systems, space resource utilization, and materials storage and processing on orbit. As space development becomes robust, its growth may well be limited by the availability of these types of utilities.

Some of the ideas put forward at the workshop that might help promote the development of space utility infrastructures include:

- Policy and legislation that promotes the development of space-based power systems for Earth.
- Space power production and transmission systems for in-space utilities.
- Legislation to facilitate the creation of a space development bank, and extended patent rights to encourage the long-term investment strategies required for utility infrastructure developments.
- Government incentives for the creation of commercial propellant supply systems in space.
- Continued technology developments of environmental control, life support, waste disposal, and recycling systems.
- Technology demonstration of low-cost resupply using launch guns (see fig. 10), cosmic snowball capture (if proven to exist), and solar system resources.

Table 1 describes many terrestrial utility systems and analogous space-based utilities that could be developed. As is evident, the development of efficient utility systems often requires long-term investments and Government anchor tenancy. However, like terrestrial utilities, space utilities are an enabler for new markets, and in a growth market, there may be a tremendous opportunity to make money providing space utility services.

Figure 10. Space utility. Continual use of a gas combustion gun-launched system for basic required materials functions like a pipeline to space. Ice projectiles could provide water and propellants on orbit with other consumable items frozen inside.

Table 1. Earth-based utility systems and possible analogous utility systems for space development.

Terrestrial Utility Systems	Analogous Space Industry-Based Utility Systems
Hydro, nuclear, fossil fuel power generation plants	Solar power satellites, nuclear power generation platforms
High-voltage line power distribution	Wireless microwave and laser power beaming
Water supplies from rain, groundwater, rivers, lakes, oceans, etc.	Water from Earth, asteroids, lunar ice
Water purification through filtration/chlorination	Closed-loop water recycling
Wastewater and sewage decontamination/disposal	Closed-loop water recycling
Natural gas and oil tankers	Propellant supply vehicles
Pipelines for water and gas	Gun-launched ice projectiles
Garbage pickup services, minesweeping	Orbital debris capture, recycling
Garbage disposal	Waste recycling and deorbit systems
Phone lines	Narrow-band wireless communications
Cable/Internet lines	Broad-band wireless communications
Global positioning system (GPS) for terrestrial location identification.	GPS for space and lunar location identification.

3.4 Human Exploration

The existing and near-term human exploration technologies for the Space Station and Space Shuttle are the baseline systems for the transportation, facility, and utility infrastructures that could be utilized by new commercial ventures early in the next century. These infrastructures are primarily Government assets, including the Space Shuttle, Spacelab, *Mir*, (and soon, *ISS*), and some commercial assets including expendable launch vehicles and SpaceHab.

It appears possible that the Government might create a market for “commercial exploration” through solicitation of communications services, scientific data, transportation, and material samples from the Moon and near-Earth asteroids to accomplish many parts of its exploration missions. This in turn would provide opportunities for industry to combine the exploration work with other commercial ventures to obtain a better total price and product.

3.4.1 Key Issues

It is believed that exploration missions can enable commercial space development, and conversely, commercial space development infrastructures can enable long-term, low-cost, human exploration missions. High flight rate/low-cost ETO transportation could enable both development and exploration missions and make it possible to expand a growing economy into space. This is a fundamentally different approach to space exploration and development than has been planned and demonstrated in the past.

Some of the ideas put forward at the workshop that might help promote continuous development of a space exploration infrastructure include:

- Exploration programs focused on identification of resources for development in addition to acquiring knowledge for scientific purposes (see fig. 11).
- Government incentives that will enable commercial exploration data and sample return missions.

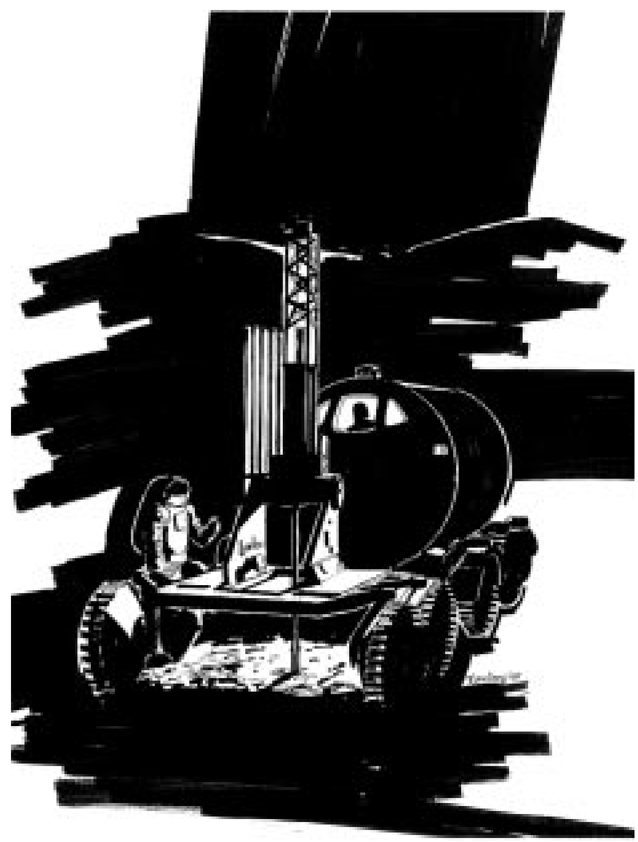


Figure 11. Exploration. Lunar ice characterization at North Pole through deep core drilling.

- Exploration technologies developed with commercial applications in mind, for use in expanding a self-supporting commercial space infrastructure.
- Leveraging of tax revenues created by healthy existing space commerce (i.e., communications) to fund exploration and development infrastructures, and provide a “tax holiday” for developing space infrastructures.

Government incentives to create a market for space exploration will eventually create new market opportunities as commercial businesses find new customers for their products and services in addition to the Government. This in turn will lower the total cost of the service needed for human exploration.

4. SPACE TECHNOLOGY AND POLICY ISSUES

4.1 Space Technology

Government technology investments should enable space development for expansion of the economy, raising the standard of living, and expansion of the tax base. Without drastic reduction in the cost of space access and infrastructure, few new space industries will become economically viable.

Lowering the cost of transportation and infrastructure will require a change in the current aerospace manufacturing and service environment from one of specialty and uniqueness to one of mass production and routiness. The Government has a critical role to play in facilitating this transition.

4.1.1 Key Issues

Various incentives, such as favorable tax policies, investments in infrastructure, joint ventures with private industry, and technology development can be used as levers to force change. Some of the ideas put forward at the workshop that might help promote continuous development of technologies for new space markets and infrastructures include:

- Technology research, development, and demonstration in proof-of-concept missions for new space industry markets and infrastructures (see fig. 12).
- Consistent evaluation and funding of new technology.
- Greater protection from disclosure risks inherent in public/private partnerships of proprietary technology information.
- Incentives that would stimulate individual motivation to discover and exploit technology development, dual-use, and collaboration opportunities.
- Technology for indexing, databasing of, and searching for technology across organizations.
- Changes in current patent law to extend the current 17-yr limit on patents to a 50-yr limit for space-related technology.

Figure 12. Technology toolbox. NASA provides tools for industry to commercialize space.

The specific issue regarding patents is the extensive time lag between the issuance of a patent and the use of that patent in a space-based business where the patent holder may see little or no return. Longer duration patents for extraterrestrial applications would encourage more R&D of processes and products to enable new space industries.

In addition to the general list of technology needs listed above, there is an equally important need to address the crosscutting technologies that will have an effect on the successful development on nearly every market and infrastructure addressed in this document. These crosscutting technologies include:

- Routine, reliable, affordable access-to-space for ETO and in-space transportation.
- Integrated health management systems for space flight vehicles.
- Autonomous and intelligent robotic systems.
- Remote continuous communications.

- High-strength, lightweight, low-cost, structures for small and large systems.
- High-efficiency power systems.
- Tether devices and technology for power generation and orbit and inclination changes.
- Nanospacecraft and biocomputing.
- Human-machine interfaces.
- Deployment mechanisms.

The role of Government must be to take a long-term view of technology investments toward creating an environment conducive to profitability. This should be possible through proper planning, policy, and legislation that provide incentives for technology developments in the areas that have both near- and long-term applications to new markets in space and the infrastructures that will support them.

4.2 Space Policy

Government policy should encourage private investments in space, enable markets, reduce risks, and provide a regulatory framework to enable profitable space-based businesses. Barriers to profitable space enterprises include the high cost of access to space, the high cost of in-space infrastructure, Government monopolization of in-space infrastructure, and an inadequate regulatory environment. Other issues of liability, property rights, and international agreements have yet to be fully addressed. If the commercial development of space is to become a reality, Government along with industry, must make resolving these issues a priority.

The lack of regulations, standards, and guidelines hobbles potential new commercial space activities. Some standards do exist, but they are almost always in reaction to situations that have already occurred. Government policy should be proactive, creating a framework in which companies can grow and expand.

Liability is an issue that concerns any new business venture. Without Government regulations that limit the exposure of companies to lawsuits, insurance costs will continue to be a hindrance to business viability. The Government should not protect companies that disregard good safety practices, but companies should not be penalized for operating within a prescribed set of regulations, standards, and guidelines.

4.2.1 Key Issues

Some of the policy ideas put forward at the workshop that might help promote new space industries include:

- Proactive policies and legislation that will identify and promote the new space industry markets and infrastructures.
- Identification of a fixed price for commercial use of existing Government space assets.
- Creation of a space development bank that will provide Government-guaranteed loans and lower the cost for commercial development of space infrastructure.

Space policy is currently expressed in documents such as the National Space Policy and the National Space Transportation Policy. Regulations exist for the licensing of commercial space transportation systems and remote sensing satellites. The NASA Strategic Plan states that the Agency must "Enable the commercial development of space…" However at this time, no cohesive, coordinated approach exists to implement space development in the broader sense at the Federal level. No single Government agency has overall leadership responsibilities for developing new space industries. NASA is focused on space exploration and space technology development. The Department of Transportation regulates existing space industries. The Department of Commerce promotes development of new air and space commerce opportunities. But no one entity or process involving the several agencies responsible for space has the overall goal to expand the U.S. economy into space to form a new and more robust space-based economy.

It appears that many organizations within the Government could play a major role in space development. Perhaps what is needed is an overall coordinated effort directed by additional space policy and legislation.

5. RECOMMENDATIONS

The recommendations from all the working groups on new markets, infrastructures, technology, and policy are summarized in this section and grouped to the greatest extent possible to indicate who should take the lead in implementing the recommendation; i.e., industry, academia, Government, or joint initiatives.

5.1 Industry

Industry should work with its industrial associations and create new associations as needed to develop new space markets and infrastructures in cooperation with the Government, but independent of Government funding to the greatest extent possible. These initiatives should include the following:

- Take a leadership role in the development of key ground-based and space-based infrastructure elements needed, especially the facilities and vehicle systems needed for low-cost reliable transportation services.
- Seek new market opportunities in space as an evolving role from analogous Earth-based services.

- Conduct outreach to capital markets and begin to cultivate an awareness and confidence conducive to securing financing.
- Identify enabling technologies that are not yet profitable enough to pursue commercially but should be developed by Government.
- Create a "Space Chamber of Commerce" with a business focus on the economic development of outer space.

5.2 Academia

Academia should concentrate on advanced research and on educating the public about the potential space development has in the near and far term. These initiatives should include the following:

- Provide the fundamental knowledge base for future space development.
- Inject space development issues into curricula.
- Share knowledge gained through publishing and presenting articles and papers.
- Lead in aggressive educational programs designed to teach the general public about the potential space development offers.

5.3 Government

Government should continue development of the basic space infrastructure necessary for future commercial ventures in space, and transition to private industry those infrastructures as they develop commercial potential where appropriate. This includes incentives for private development of new space infrastructures to help create and support the new space industry markets. These initiatives should include the following:

- Establish a fair and consistent access and pricing policy for commercial use of Government space assets; i.e., space shuttle and *ISS*.
- Develop a plan to build space infrastructure similar to the way Government has been involved in the highway system, air traffic control system, railroads, power, water, etc.
- Demonstrate proactive space industry initiatives through consideration of actions such as anchor tenancy, tax credits, consortium support, trade promotion, education, and endorsement to promote private investments in space development.
- Facilitate the creation of innovative financing opportunities, such as a space development bank, limited liability insurance, and Government-guaranteed loans to reduce risk, and cost of new space investments.
- Extend patent rights; e.g., from 17 to 50 yr, to encourage the long-term investment strategies required for space industry developments.
- Establish clear certification procedures for the provision of commercial parabolic flights for both R&D and passengers.
- Simplify flight certification standards for new suborbital and orbital reusable vehicles, with overflight and reentry regulations merged with air traffic control.
- Establish proactive policy and legislation that encourages utilization of *ISS* standards, technology, tooling, and manufacturing facilities.
- Consider innovative nearer-term steps such as adding a commercial module to Space Station as a commercial consortia partner to the *ISS* program.
- Provide near-term allocation of proper bandwidth for power transmission.
- Establish policy and legislation that promote the development of space-based power systems for Earth.
- Initiate a comprehensive solar system geological survey to determine potentially profitable resources and to support asteroid detection and characterization.
- Provide incentives for commercial identification and extraction of samples from near-Earth asteroids and the Moon.
- Establish policy that supports extraterrestrial mining claims and strengthens the property rights of industry to their investments in space.
- Establish goals and incentives for an industrial facility on the Moon that will support the growth of a space infrastructure for stable Earth/lunar traffic, propellants, materials and science.
- Transition development and operational activities from Government to industry when they have matured sufficiently, as is now being done with the Space Shuttle and with the Government's procurement of commercial launch services.
- Contract with industry to the greatest extent possible for services, equipment, products, and data, to satisfy space science, exploration, weather, and military needs.
- Establish safety, rescue, and escape system standards for the general public's use of space transportation and space facilities.
- Set policy on governance, zoning, administration, and security of space facilities.
- Leverage tax revenue from mature and profitable space

commerce to fund space exploration and infrastructure development initiatives.

- Promote the macroeconomic effects of space development.
- Provide policy and resources to stimulate and enable industry to produce commercial products and services off-Earth as is done in the development of any other new market.
- Establish appropriate organizations within NASA; e.g., an office at each NASA Center devoted to space commerce with a liaison matrixed to each major project.
- State the operational requirements for space exploration and development, and let business and industry respond to its incentives.
- Develop new project plans that include a commercialization phase for transition of the operation of new systems to industry, and requires up-front business planning prior to the development of the system or demonstration mission.

5.4 Joint Initiatives

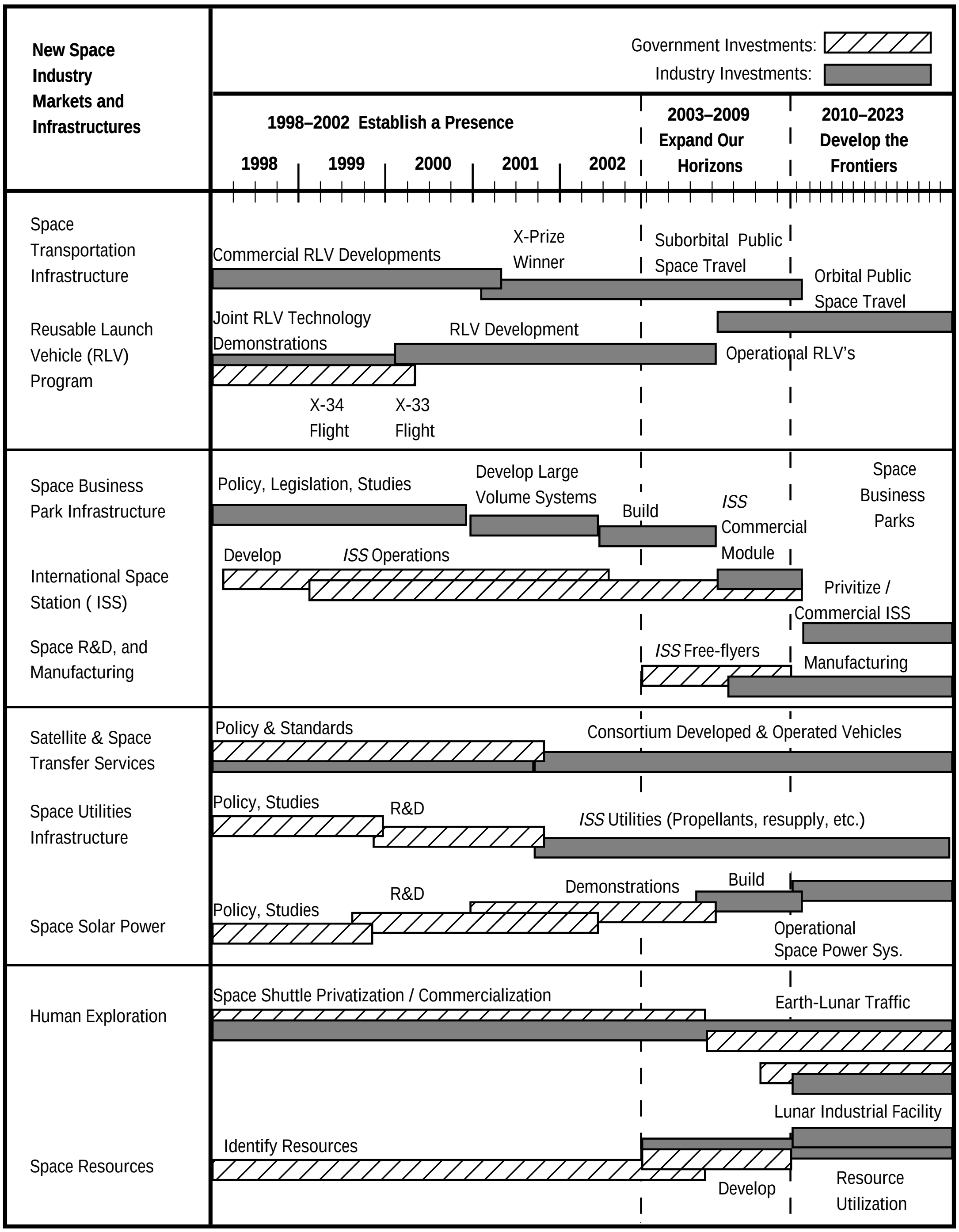
Joint consortia would provide a mechanism for addressing many of the issues raised in the previous section. Industry would identify barriers to the development of new space industries, and the Government would direct its considerable resources to removing those barriers. Government support could include basic R&D, commercial use of its facilities, changes to policy and regulation, adherence to standards, and technology development. Specific recommendations for possible joint initiatives are as follows:

- Develop and demonstrate technology for large-volume construction systems, partial gravity (rotating) mechanical systems, closed-loop life support systems, large window systems, and autonomous and human tended free-flyer microgravity platforms.
- Develop a highly operable, highly reusable ETO rocket engine, with hundreds of flights between overhauls or criticality 1 failures.
- Develop X-vehicles and facilities for demonstration of in-space transportation technologies for orbital transfer and orbital maneuvering including high-energy aerobraking and aerocapture systems.
- Develop more ETO and suborbital X-vehicles to demonstrate new technologies and new approaches to transportation.
- Develop X-vehicles that can be integrated into the existing airline infrastructure for passenger transportation to space.
- Develop and demonstrate propulsion technologies to include high-energy density propellants, solar-thermal engines, steam rockets, nonchemical propulsion, air collection and enrichment systems, nuclear technologies, and propellantless transportation technologies including electrodynamic tethers and momentum exchange tether systems.
- Continue technology development for space power production and transmission systems for in-space utilities.
- Continue development of environmental control, life support, waste disposal, and recycling systems.
- Investigate advanced concepts for low-cost resupply (e.g., using launch guns, cosmic snowball capture, and/or in situ resources).
- Conduct R&D for orbital debris mitigation and cleanup for protection of space assets.
- Develop material identification, extraction, separation and processing systems, including in situ processing demonstrations.
- Establish satellite and vehicle standards, and demonstrate the technology for satellite servicing, liquid propellant storage, reusable in-space transportation, module replacement, and maintenance.
- Establish payload standards designed to reduce qualification requirements and increase automation.
- Design future launch vehicles with reduced launch loads to reduce payload environment testing requirements.
- Develop industry standards for crew licensing, liability insurance, building codes, orbital operations, and passenger training.
- Develop high-fidelity telepresence technology to advance virtual reality, remote control, and navigation for inspection, assembly, maintenance and rescue of spacecraft, and to help operators and others experience space from the ground.
- Conduct basic research, technology development, and demonstration missions based on the new markets identified by industry.
- Develop microgravity tools, manufacturing equipment, and construction systems, including autonomous and remote systems for assembly—this includes adaptation of mining technology to microgravity and low-gravity environments.

- Promote public educational programs—domestically and internationally—of the environmental, societal, and safety issues for *SSP* systems and space development.
- Focus future exploration programs on the identification of resources, and the development of technologies with dual-purpose commercial applications in mind, in addition to acquiring knowledge for scientific purposes.
- Form joint industry/academia/Government consortia to accelerate technology and demonstration missions.
- Set up industry/Government/academia teams to address all the roles identified in the previous sections to ensure full participation and full support of key activities by both parties.
- Set up industry/academia teams to focus on characterizing potential new markets with valid market surveys.
- Work toward a consistent vision for the development of space.

The possibilities that could be realized through a proactive initiative from the many organizations represented in this study, and the many others referenced as having a significant role to play, are tremendous. Often what is needed is a vision of what those possibilities are and a plan for how to get there. It was the intent of this activity to begin the process of identifying the many possibilities for space development and the actions that must be taken to turn them into reality. Appendix A provides a brief roadmap that lays out a possible future for when the markets described in this report could emerge, develop, and begin to integrate to form the infrastructures required for the economic development of new space industries.

APPENDIX A—A Roadmap for Implementation



This timeline is a composite generated from the inputs provided from each of the working groups to form one integrated potential roadmap for implementation over the next 25 yr.

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13. ABSTRACT *(Maximum 200 words)*

New Space Industries For the Next Millennium is a final report of the findings from the New Space Industries Workshop held in Washington, DC, in February 1998. The primary purpose of this workshop was to identify what must be done to develop new markets, and to generate plans, milestones and new organizational relationships designed to facilitate the goal of space development. This document provides a summary report on the results of that workshop and is not intended as a statement of NASA or government policy.

Previous studies had shown great potential for the development of new markets in space (e.g., travel and entertainment, space solar power, satellite and space transfer services, research and development in space, space manufacturing, and space resources), and a great need for coordination and formation of infrastructures (e.g., space transportation, space business parks, and space utilities), to facilitate the growth of new space businesses. The New Space Industries Workshop brought together government, academia, and industry participants from several previous studies and other professionals interested in the development of space for commercial purposes. Their participation provided input into the role of government and industry in space development as well as the technology needs that will enable space development.

The opening of the frontier of space, not just to government missions but to private individuals and commercial business, is a challenge of overarching importance. It is our hope that the workshop and this final report continue in earnest the process of identifying and overcoming the barriers to large-scale public access and development of space in the early years of the next century.

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